University of Colorado
Denver

Aakash Sahai

Uniquely enabled

Science initiatives

CO_2 laser & **e^-** beam

BNL-ATF

Novel Initiatives

- CO_2 Laser **Positron** Acceleration
  [e^- beam driven e^+-e^- pair-plasma injected into CO_2 LWFA]

- CO_2 Laser **RITA** Ion acceleration
  [Argon doped with Hydrogen]

- **sub-fs** modulation of e^- beam
  [Tunable beam-dump and Energy recovery]

Laser Positron Accelerator Collaboration

proof-of-principle expt.s

Fermilab

TECH-X
SIMULATIONS EMPOWERING YOUR INNOVATIONS

MICHIGAN ENGINEERING
CENTER FOR ULTRAFAST OPTICAL SCIENCE

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BELLA

LaserNetUS

Proposal Schematic - Laser Positron Acc.

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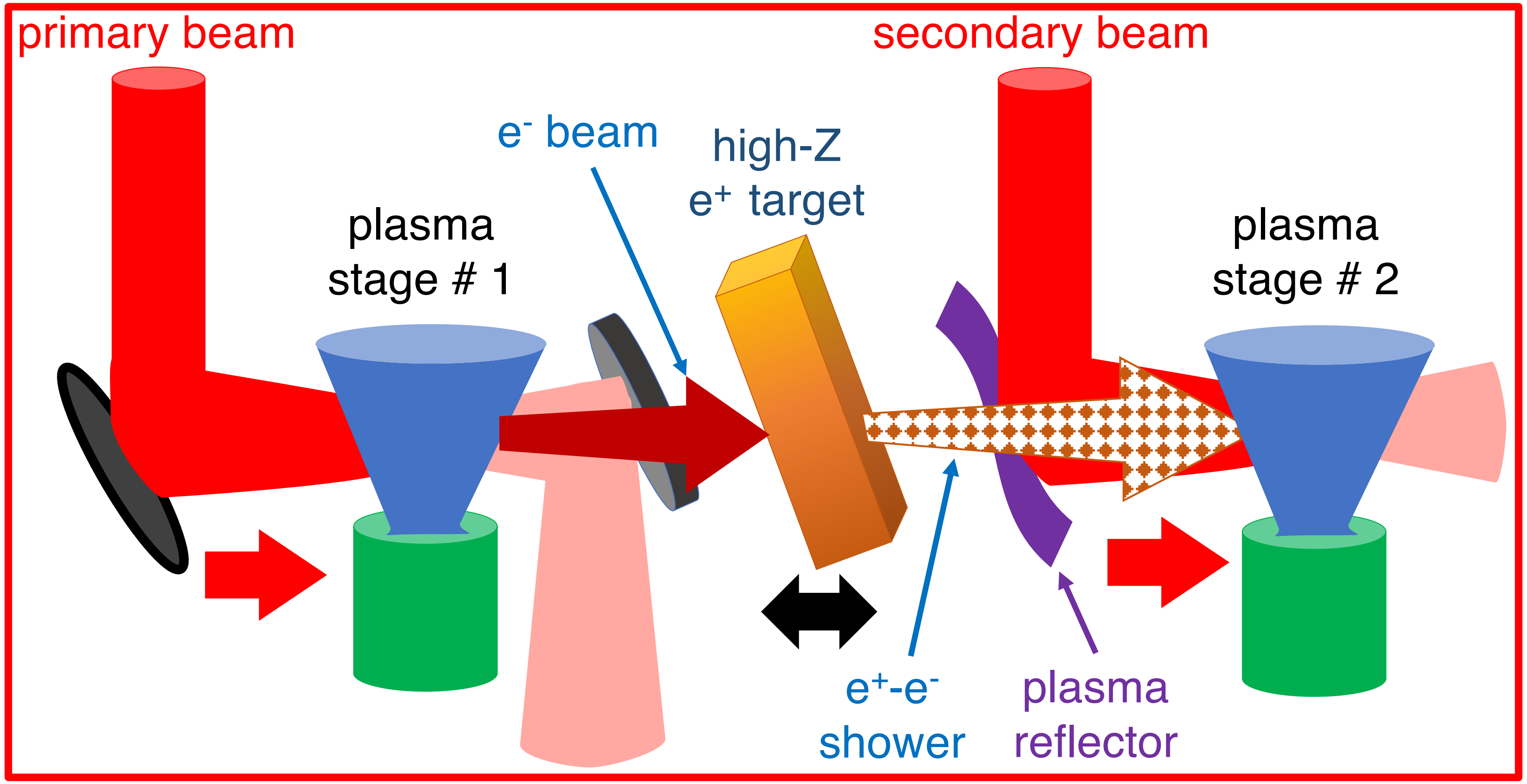

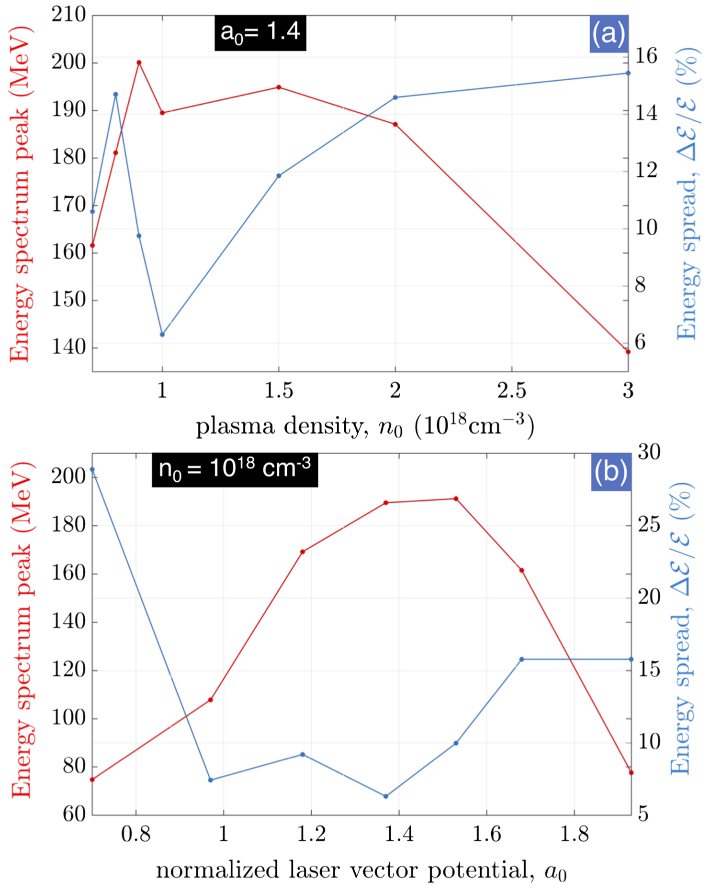

PHYSICAL REVIEW ACCELERATORS AND BEAMS **21,** 081301 (2018)

Quasimonoenergetic laser plasma positron accelerator using particle-shower plasma-wave interactions

Aakash A. Sahai*

Department of Physics and John Adams Institute for Accelerator Science, Blackett Laboratory, Imperial College London, SW7 2AZ, United Kingdom

Laser **Positron** Acc. Collaboration

- **post-process** particle-showers - using laser-driven target
  [patent pending] (particle-showers – preferably laser-driven – BUT more stable with e- beam)

- **types** of particle-shower post-processing
  – segregation of particle species (trapping, transverse cooling, dual-bunch etc…)
  – phase-space & spectral shaping using laser target stage
  (mono-energization, acceleration, deceleration, focusing, de-focusing)

- optimize **capture** and **acceleration** of MeV-scale shower particles (denser part of the shower spectra) – applications to crystal radiation and material science

- **focus**, **segregate** and **trap** 10 to 100 MeV-scale shower particles – use active plasma lens

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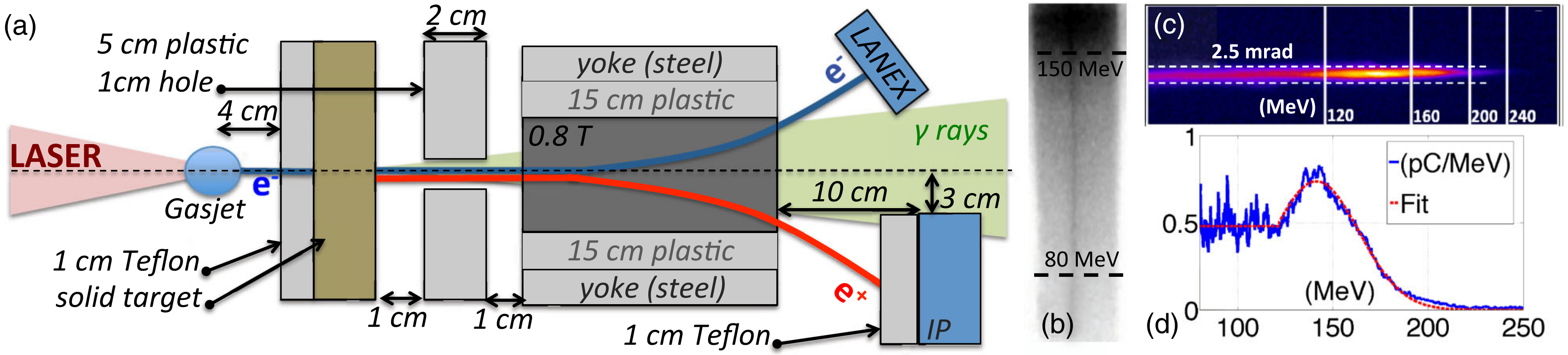
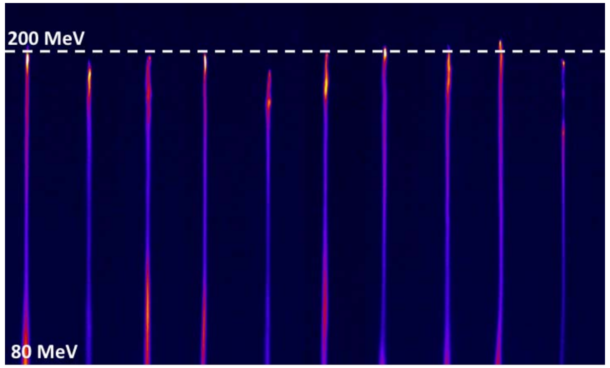
Laser **shower production** experience - Laser Positron Acc.





Supplementary material Figure 1: Typical series of ten spectra of the laser-accelerated electron beam, as recorded on the LANEX screen before the insertion of the solid target. The overall electron beam charge fluctuated within less than 10% and the peak electron energy was consistently of the order of 200 MeV.

Mat.	d (mm)	θ_{e^+} (mrad)	$N_{\rm exp} \times 10^5$	$N_{\rm sim} \times 10^5$	$N_T \times 10^5$
Cu	5.3	2.3 ± 0.2	0.3 ± 0.1	0.3	31
Sn	6.4	2.7 ± 0.3	0.6 ± 0.1	0.6	63
Ta	2.8	2.7 ± 0.3	2.1 ± 0.3	2.1	190
Pb	4.2	3.5 ± 0.4	2.3 ± 0.3	2.3	240
Ta	1.4	2.3 ± 0.2	0.8 ± 0.2	0.8	78
Ta	4.2	2.7 ± 0.3	3.8 ± 0.3	3.9	350
Pb	2.2	3.0 ± 0.3	0.7 ± 0.2	0.7	60
Pb	2.8	3.3 ± 0.3	1.1 ± 0.3	1.1	122

increases for materials with higher atomic number. This trend is quantitatively confirmed by integrating the experimental spectra in the range $90 < E_{e^+}(\mathrm{MeV}) < 120$ (see Table I and Fig. 3). Within this energy range, a maximum positron number of $(2.30 \pm 0.28) \times 10^5$ is obtained for the material with the highest Z (Pb). Fitting the data keeping j as a free parameter, we obtain a best fit for $j = 2.1 \pm 0.1$

PRL **110,** 255002 (2013) PHYSICAL REVIEW LETTERS week ending 21 JUNE 2013

Table-Top Laser-Based Source of Femtosecond, Collimated, Ultrarelativistic Positron Beams

G. Sarri,[1] W. Schumaker,[2] A. Di Piazza,[3] M. Vargas,[2] B. Dromey,[1] M. E. Dieckmann,[1] V. Chvykov,[2] A. Maksimchuk,[2] V. Yanovsky,[2] Z. H. He,[2] B. X. Hou,[2] J. A. Nees,[2] A. G. R. Thomas,[2] C. H. Keitel,[3] M. Zepf,[1,4] and K. Krushelnick[2]

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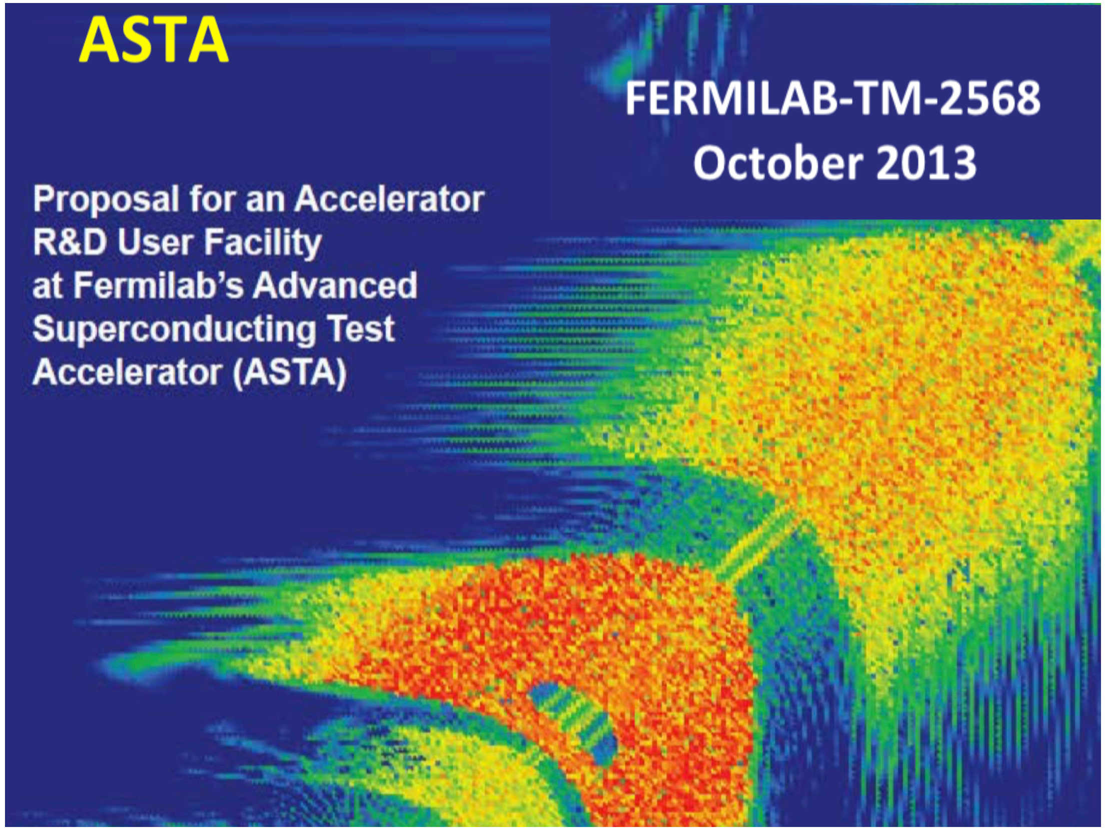
Channeling Radiation / Undulator - Laser Positron Acc.

PHYSICS LETTERS Volume 57, number 1 17 May 1976

ON THE THEORY OF ELECTROMAGNETIC RADIATION OF CHARGED PARTICLES IN A CRYSTAL

M.A. KUMAKHOV



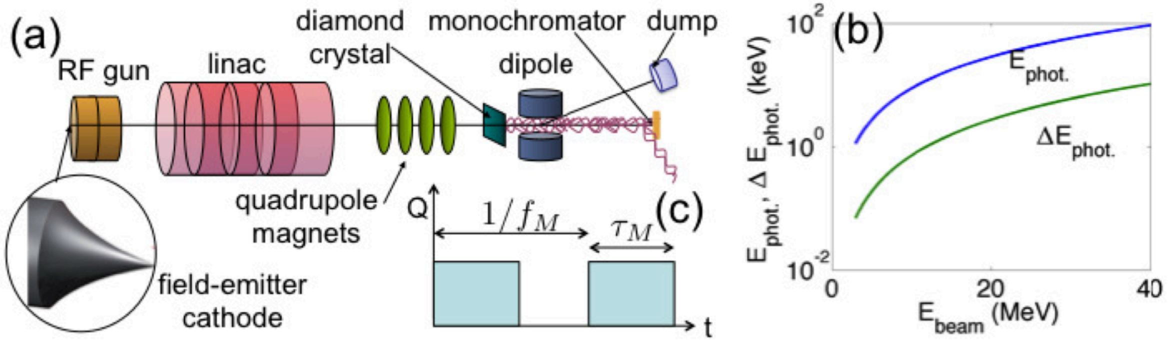


Figure 6: The layout of the X-ray channeling radiation source experiment in the 50 MeV area of ASTA [13].

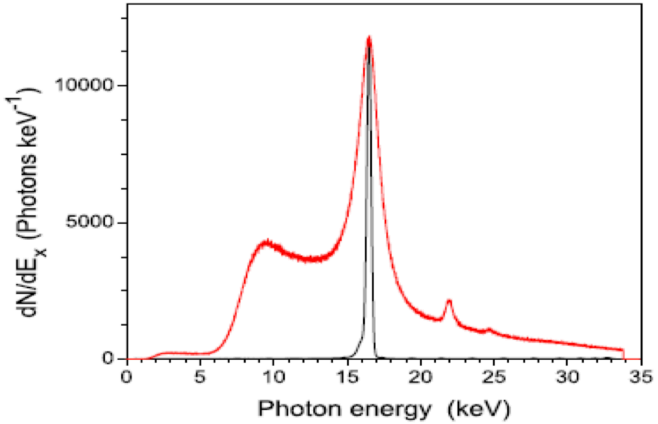


Figure 2: Observed spectrum of channeling radiation for transitions in (110) plane of diamond crystal at an electron energy of 14.6 MeV. Red: natural spectrum; black, monochromatized by Bragg reflection to remove the wings of the CR line and the Bremsstrahlung background [6].

Channeled **Annihilation** γ Imaging - Laser Positron Acc.

PHYSICAL REVIEW B VOLUME 3, NUMBER 3 1 FEBRUARY 1971

Channeling of Positrons

J. U. Andersen* and W. M. Augustyniak
Bell Telephone Laboratories, Murray Hill, New Jersey 07974
and
E. Uggerhøj
Institute of Physics, University of Aarhus, 8000 Aarhus C, Denmark
(Received 7 July 1970)

IEEE Transactions on Nuclear Science, Vol. NS-26, No. 3, June 1979

CHANNELING RADIATION FROM POSITRONS

M. J. Alguard,* R. L. Swent,* R. H. Pantell,* B. L. Berman,† S. D. Bloom,† and S. Datz††

VOLUME 77, NUMBER 10 PHYSICAL REVIEW LETTERS 2 SEPTEMBER 1996

Increased Elemental Specificity of Positron Annihilation Spectra

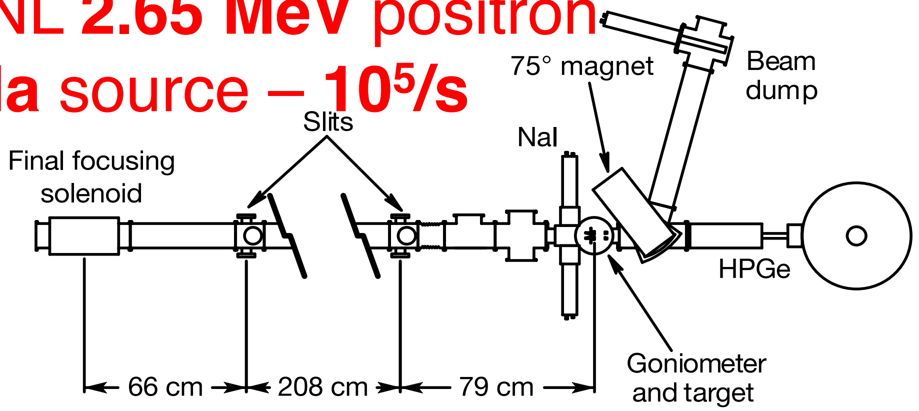
P. Asoka-Kumar,[1] M. Alatalo,[1] V. J. Ghosh,[1] A. C. Kruseman,[2] B. Nielsen,[1] and K. G. Lynn[1]
[1] *Brookhaven National Laboratory, Upton, New York 11973*
[2] *IRI, Delft University of Technology, Mekelweg 15, NL-2629JB Delft, The Netherlands*

Spatial sampling of crystal electrons by in-flight annihilation of fast positrons

A. W. Hunt*†, D. B. Cassidy*†, F. A. Selim‡, R. Haakenaasen§, T. E. Cowan†, R. H. Howell†, K. G. Lynn‖ & J. A. Golovchenko*¶#

NATURE | VOL 402 | 11 NOVEMBER 1999

LLNL **2.65 MeV** positron
^{22}Na source – **10^5/s**



…development of practical atomic-scale channeling measurements of electronic spin densities, and momentum profiles in addition to valence and bonding e$^-$ density maps.

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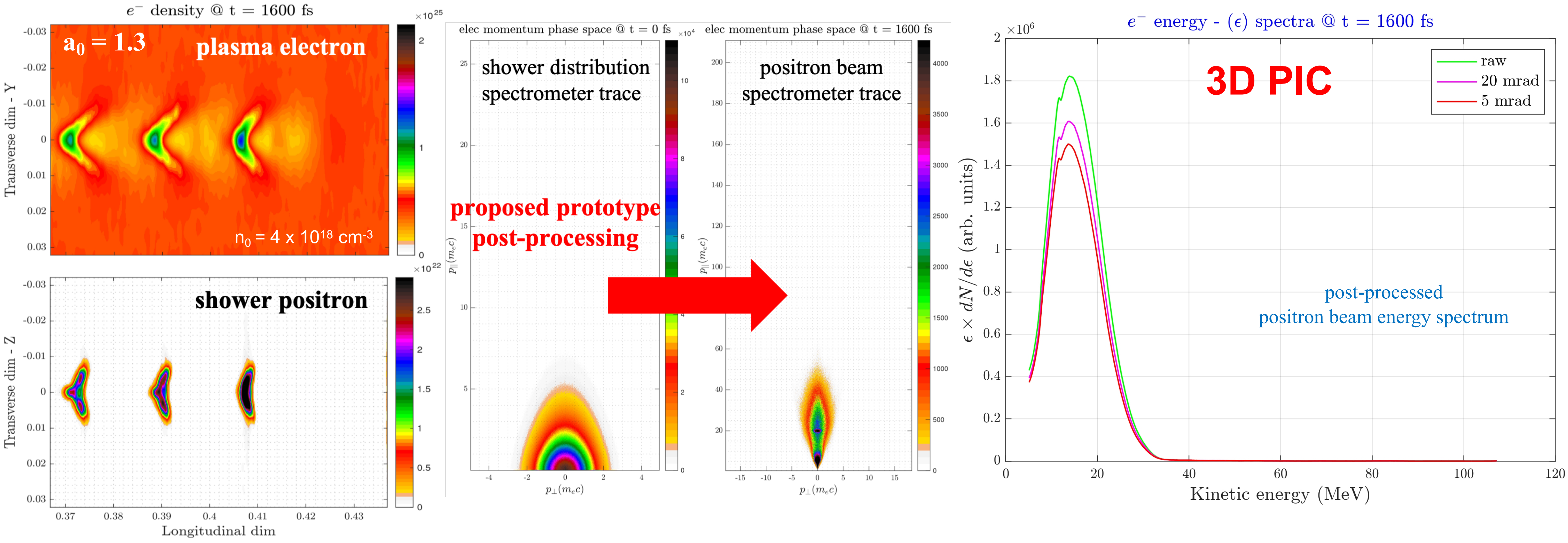
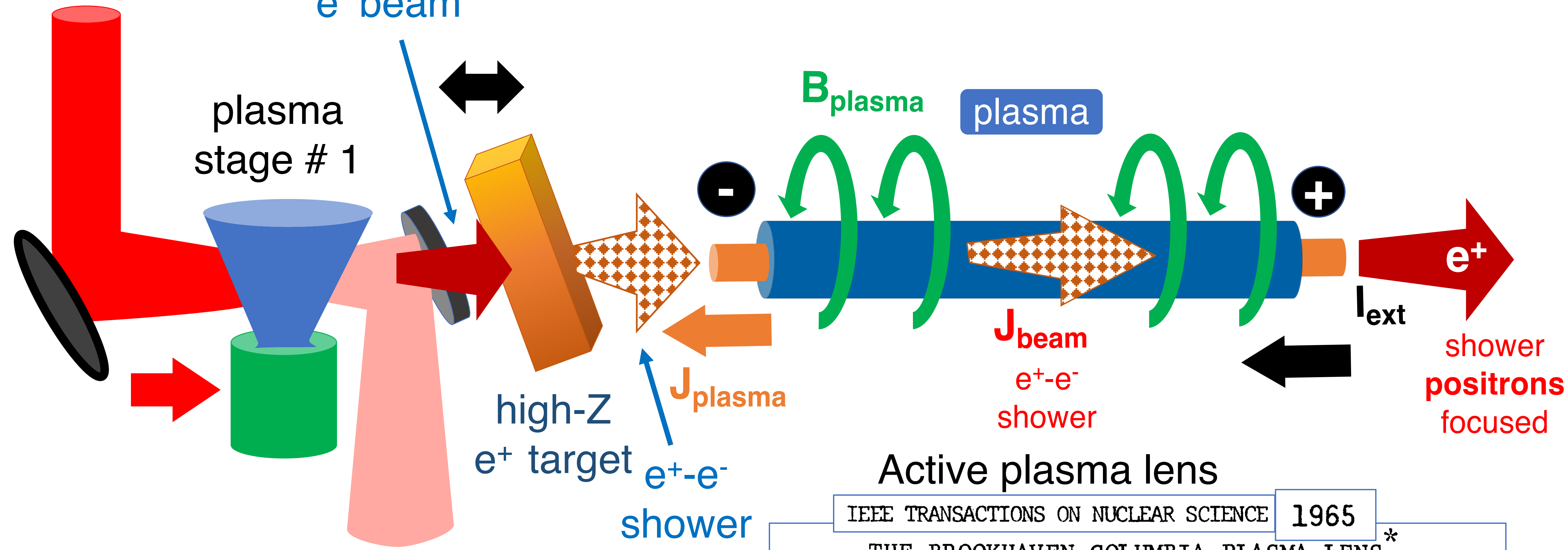
LaserNetUS proposed effort using BELLA HTW



3D PIC EPOCH simulations of BELLA HTW e^+ LPA

University of Colorado Denver

shower species – segregation & focusing
[phasing RF voltage & primary beam]



Active plasma lens

IEEE TRANSACTIONS ON NUCLEAR SCIENCE 1965

THE BROOKHAVEN-COLUMBIA PLASMA LENS*

E.B. Forsyth, L.M. Lederman † and J. Sunderland †
Brookhaven National Laboratory
Upton, L.I., N.Y.

BNL-ATF CO_2 Laser **Positron** Acceleration

- e^- beam driven e^+-e^- pair-plasma - more stable, more systematic study – **need e^+ spectrometer** (or prog. flip magnet PS)

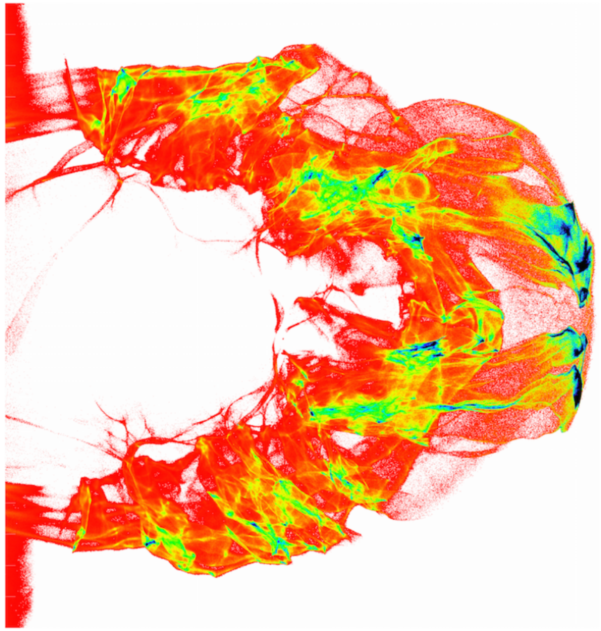
- injected into CO_2 LWFA – need full-power CO_2 on BL # 2

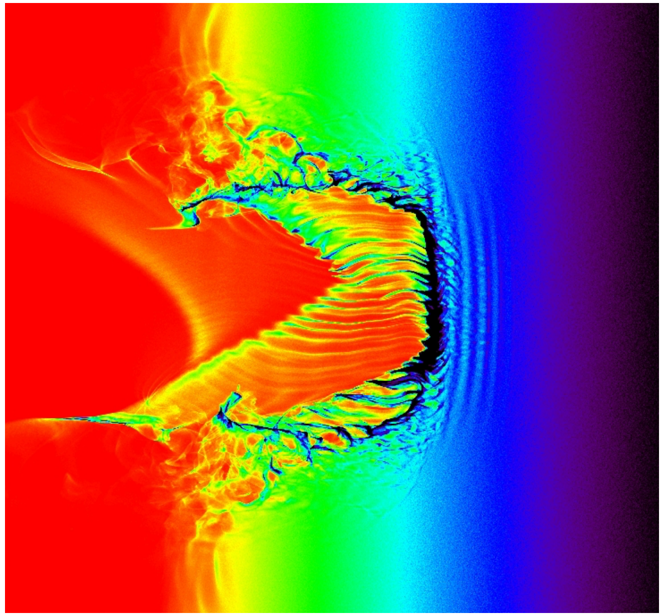
- CO_2 LWFA – bigger wakefield – **more spatial overlap with shower** - more positrons trapped for a give electron beam energy

Relativistically Induced Transparency Acceleration (RITA)

using shaped density gradients

in a **2-species** mixed-Z gas





Relativistically Induced Transparency Acc.,
Sahai, et. al., **Phys. Rev. E 88**, 043105 (2013)

University of Colorado Denver

Critical layer interactions in low-Z vs high-Z plasma

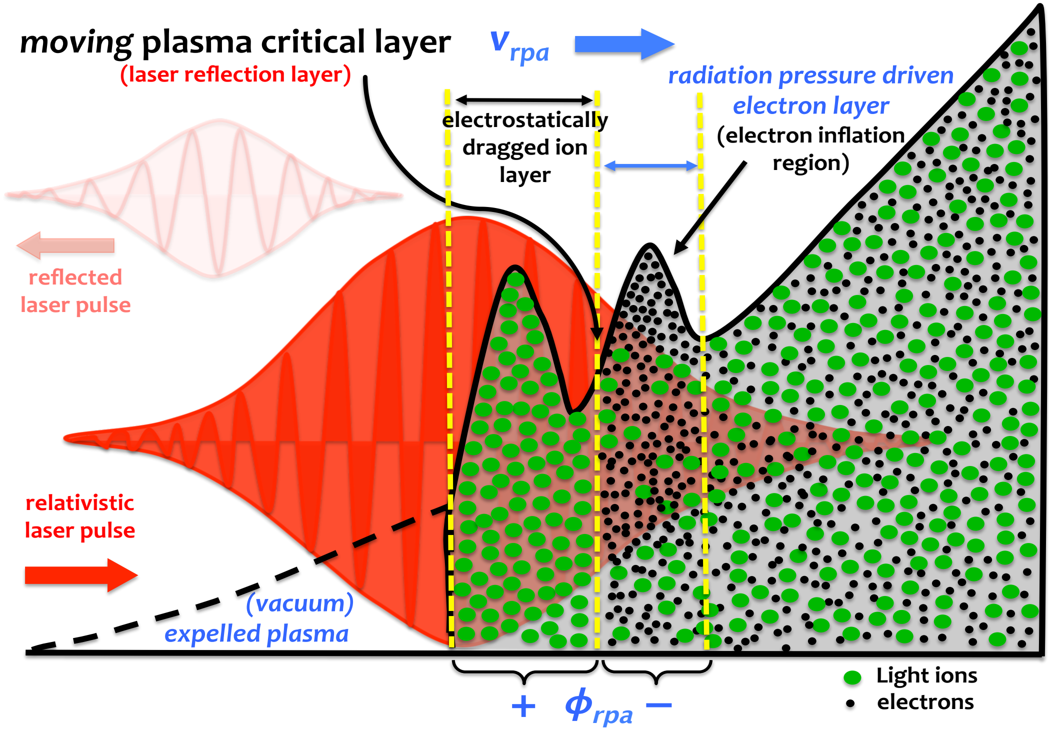
ion inertia dictates
critical layer
laser-plasma interactions

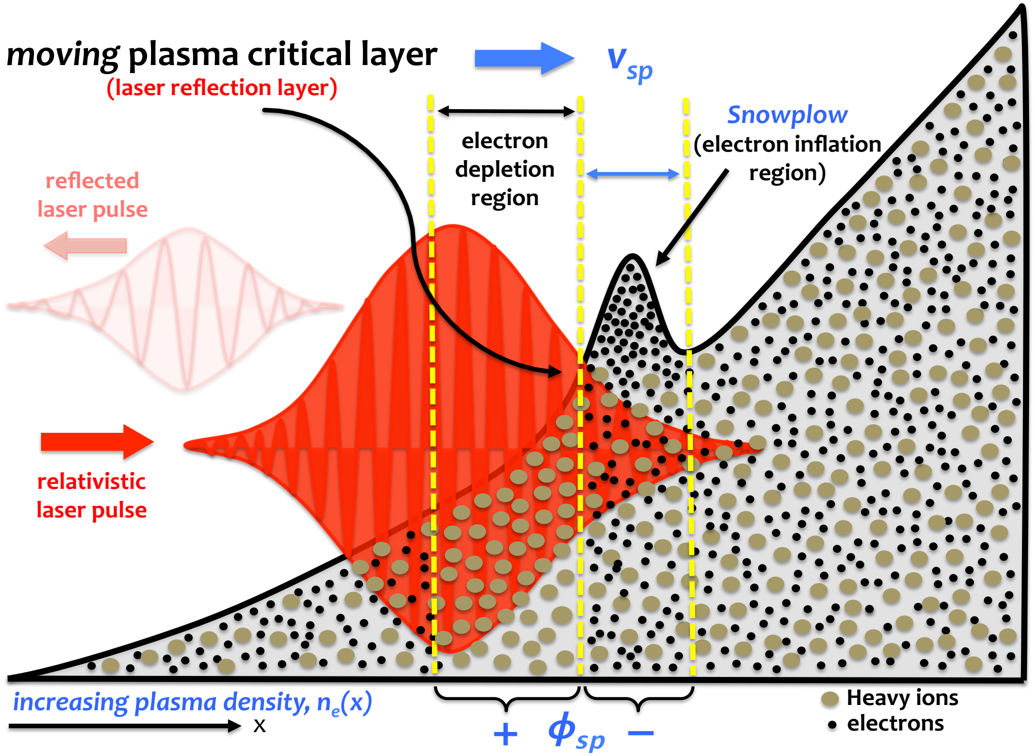
Motion of the plasma critical layer during relativistic-electron laser interaction with immobile and comoving ion plasma for ion accelerationa)
Aakash A. Sahai
Citation: Physics of Plasmas **21**, 056707 (2014); doi: 10.1063/1.4876616

laser propagation
purely by electron dynamics

Radiation Pressure Acc

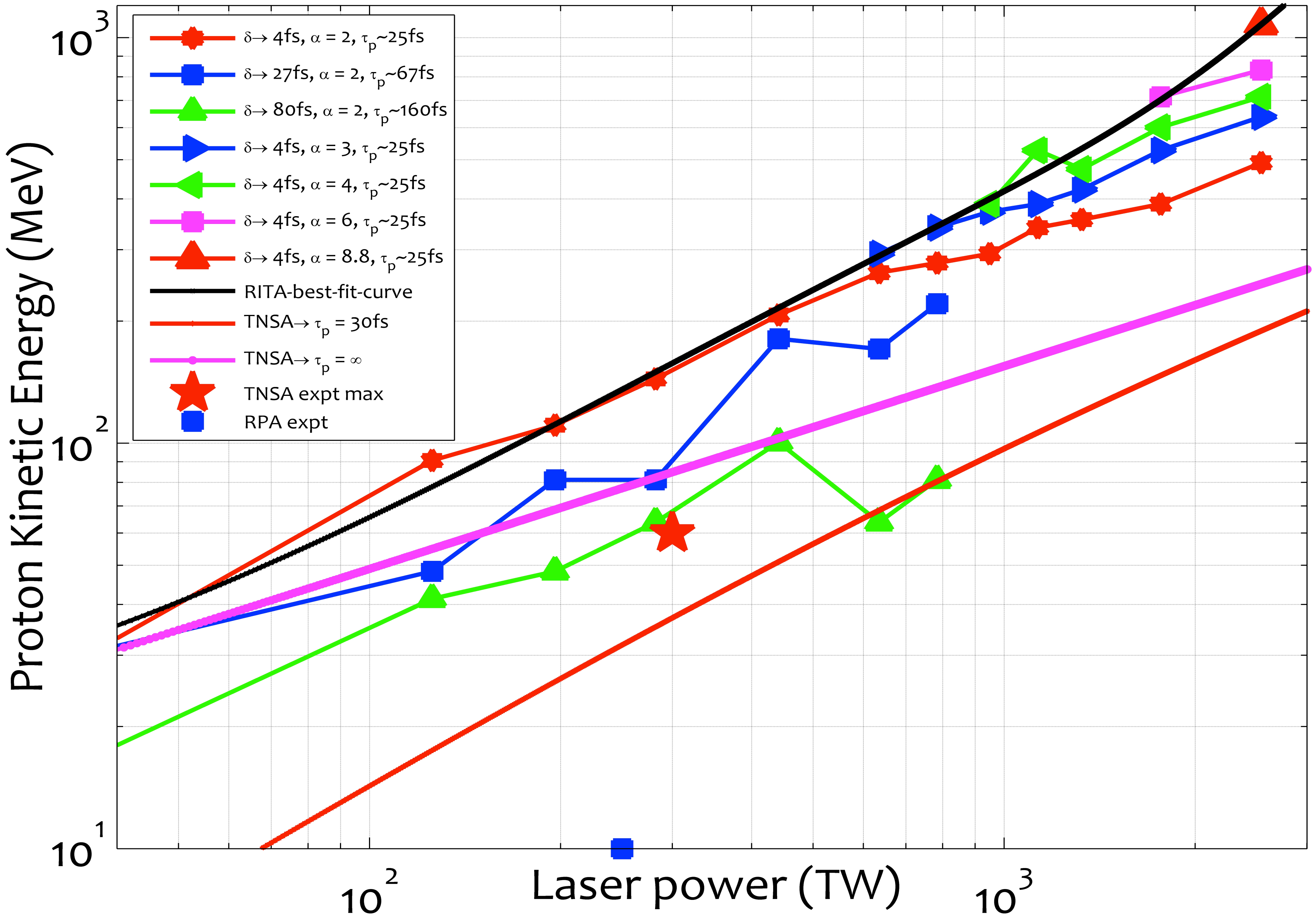
RITA



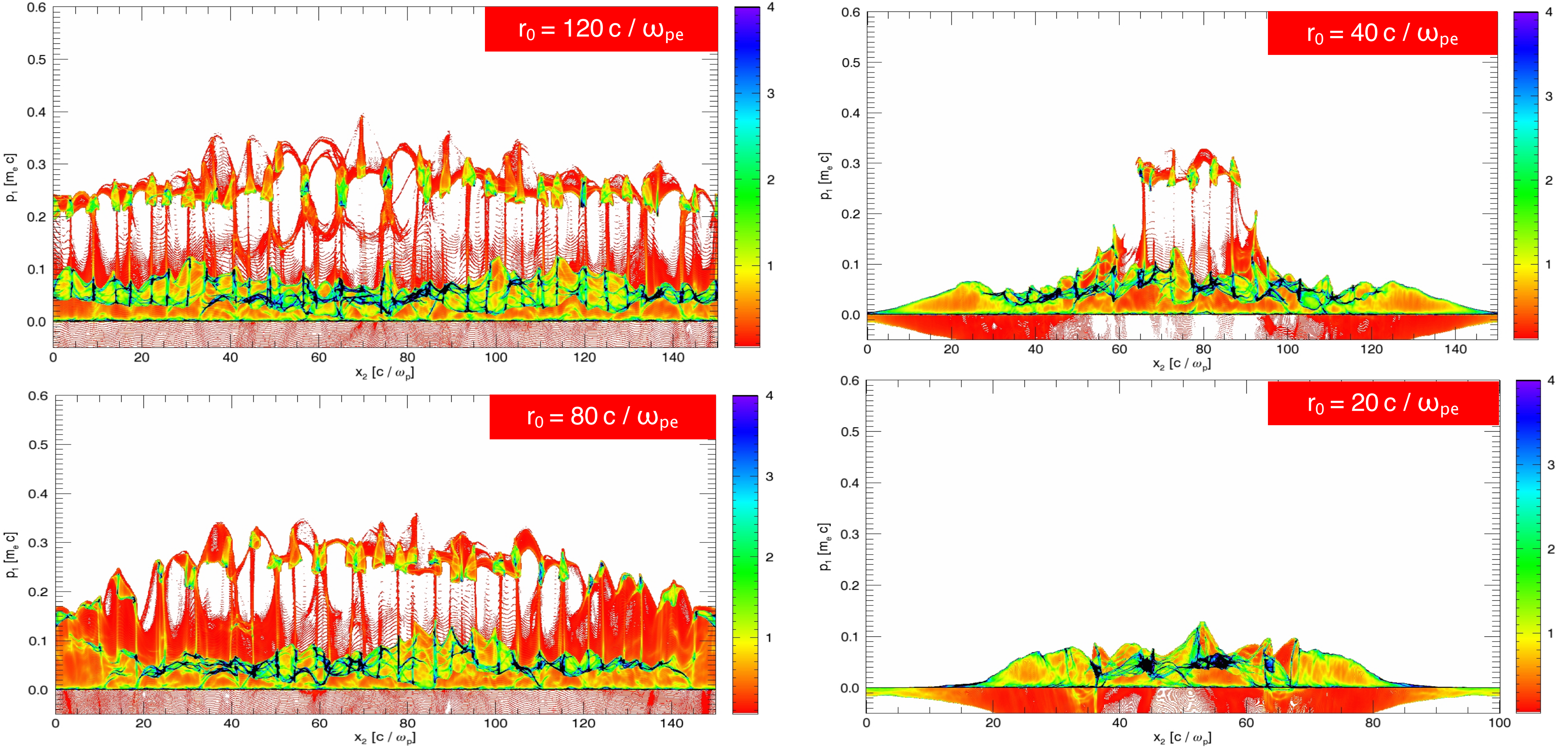


RITA Scaling – Ti:Sapphire Laser

University of Colorado Denver



RITA filamentation mitigation – matched laser-spot



5TW CO_2 laser – **a_0 = 1** regime

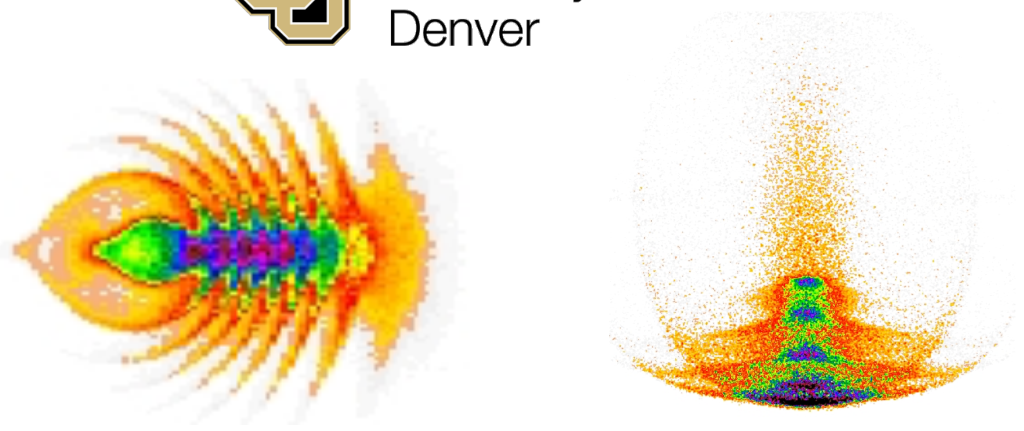
- gas-based laser-plasma ion acceleration schemes – a promising pathway
- Hole-boring needs higher densities (at high intensities) – avoid target breaching
- can use 2-ion species (CO_2 laser allows 10^{19} cm^{-3} critical density)
- **Ar** + **Hydrogen** mixes are common industrial mix
- Promise of tunable **10MeV** proton beams with 5TW

Plasma Beam-dump & Energy Recovery

The University of Manchester

University of Colorado Denver

Stony Brook University

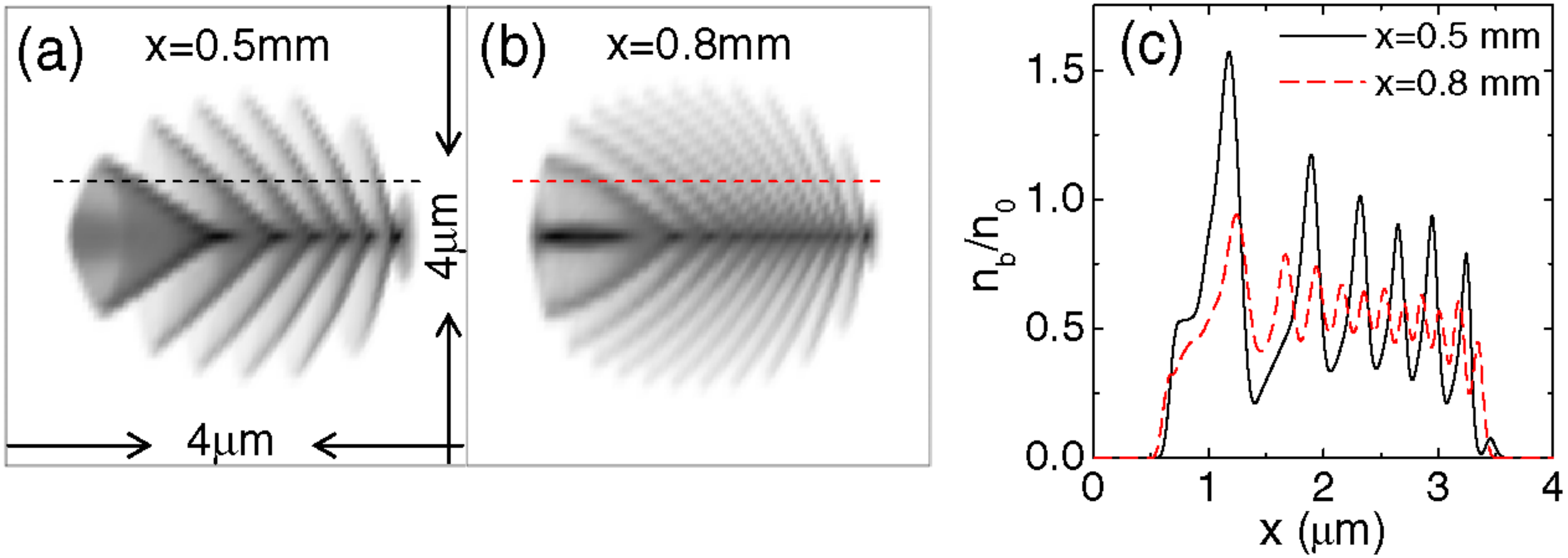


Tunable Beam-dump using Collective Fields in Plasma: Controlling Radiation Background and Stopping Power

BROOKHAVEN NATIONAL LABORATORY

Plasma beam dump – PRAB, **13,** 101303 (2010)

Toshi Tajima



500 MeV

$$n_e = 2n_b \approx 4.4 \times 10^{19}\ \mathrm{cm}^{-3}$$

beam betatron frequency

$$\Omega_b = \omega_{pe}/\sqrt{2\gamma}$$

beam spot-size oscillation solution

$$\sigma_T(x, \xi) = \sigma_T(0, \xi)|\cos[\Omega_{b0}(1 + \xi/\sigma_L')x/c]|.$$

beam spot-size modulation period

$$\eta = \frac{\pi c \sigma_L'}{\Omega_{b0} x} = \sqrt{\frac{\gamma}{2}} \frac{\sigma_L'}{x} \lambda_{pe},$$

σ_r = 50 um, σ_z/c = 500 fs, Q = 200 pC, n_0 = 1e16 cm^{-3}

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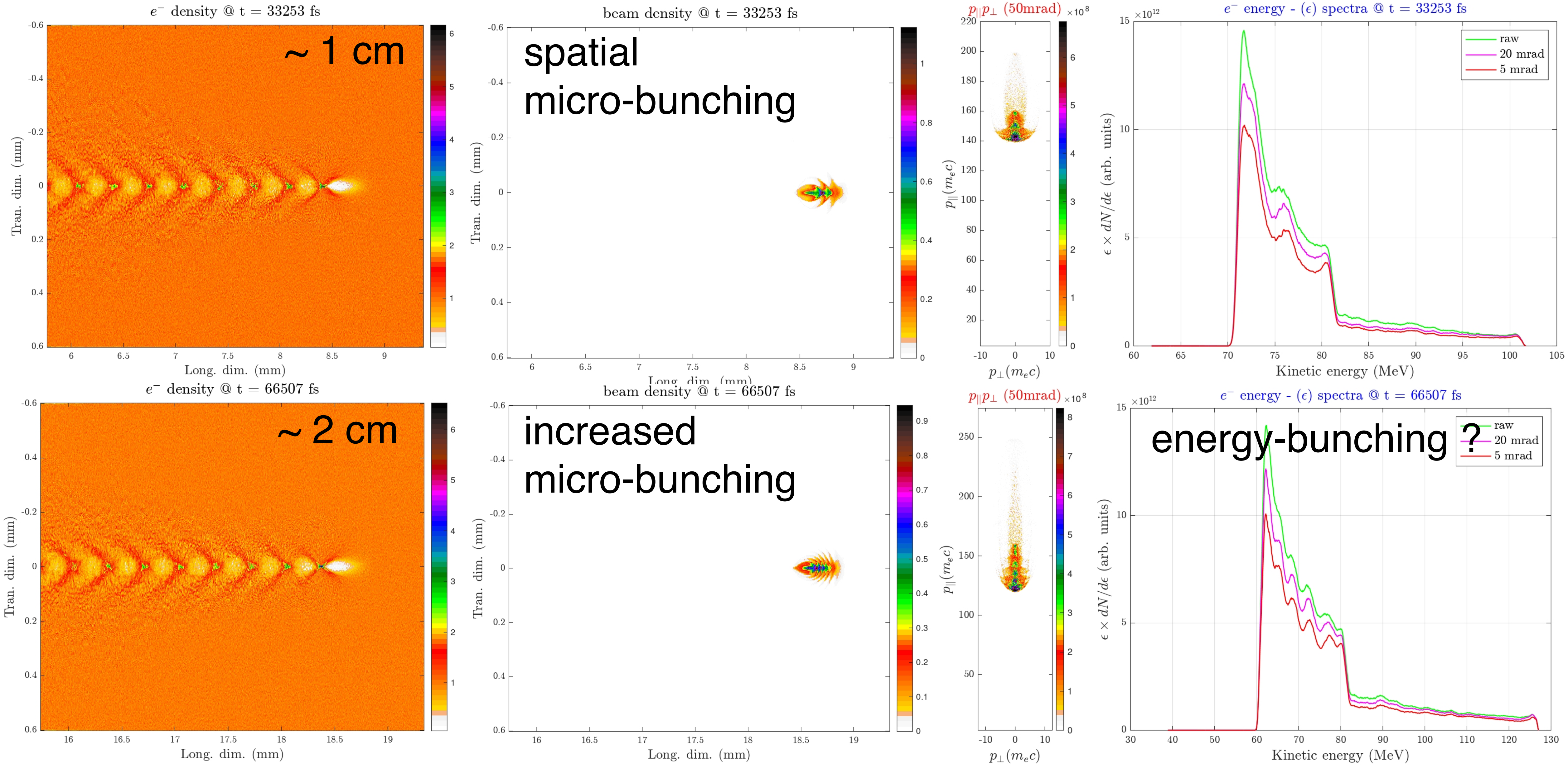

σ_r = 50 um, σ_z/c = 500 fs, Q = 200 pC, n_0 = 1e16 cm^{-3}

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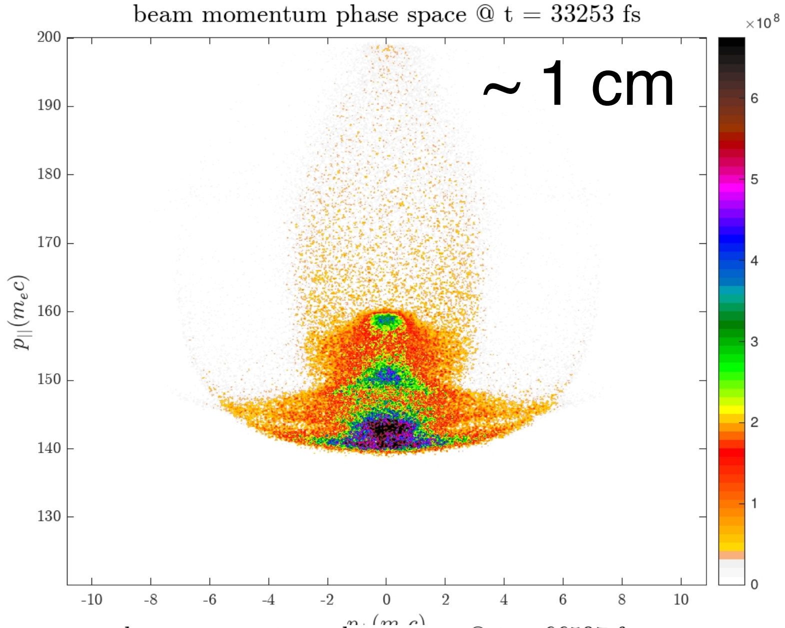
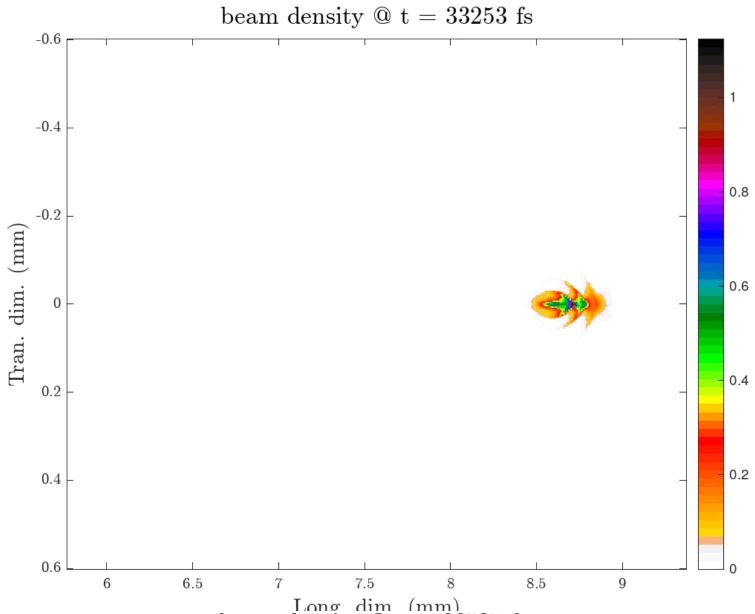
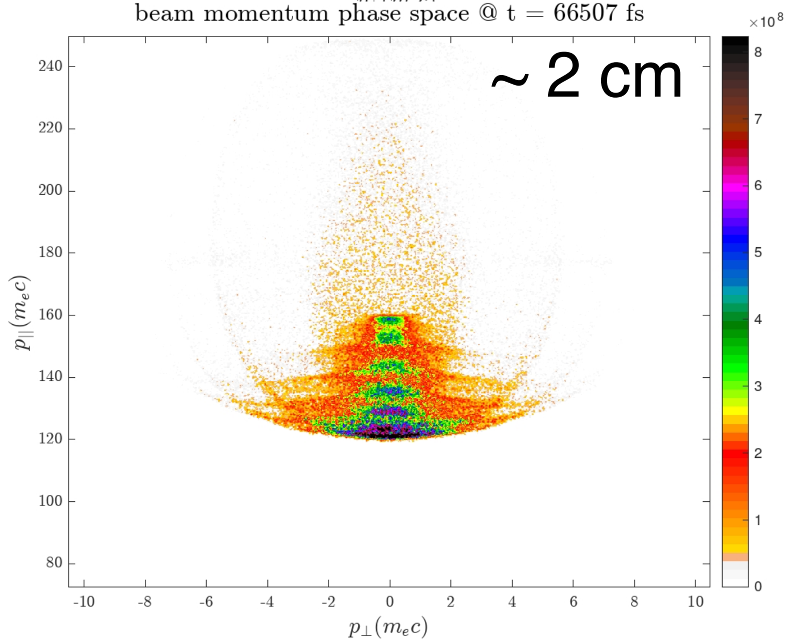


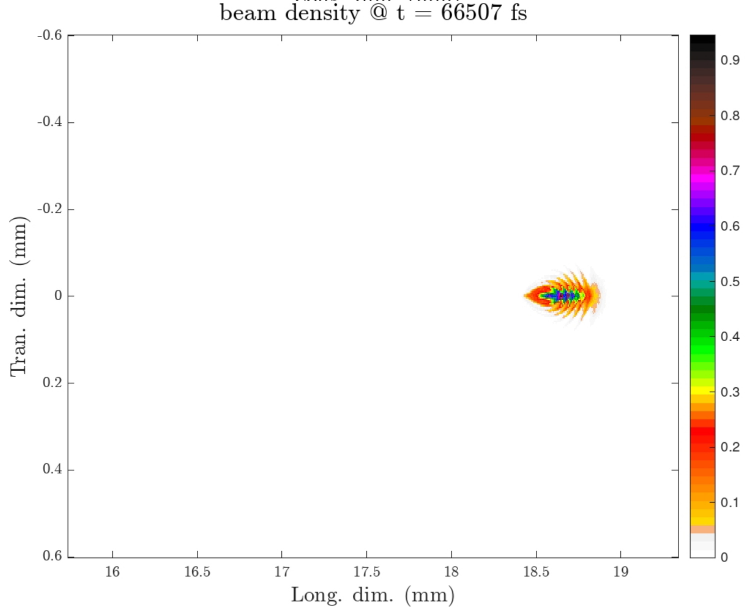


energy-bunching

in correspondence with

spatial micro-bunching





BROOKHAVEN NATIONAL LABORATORY

BL# 2 - BNL-ATF setup

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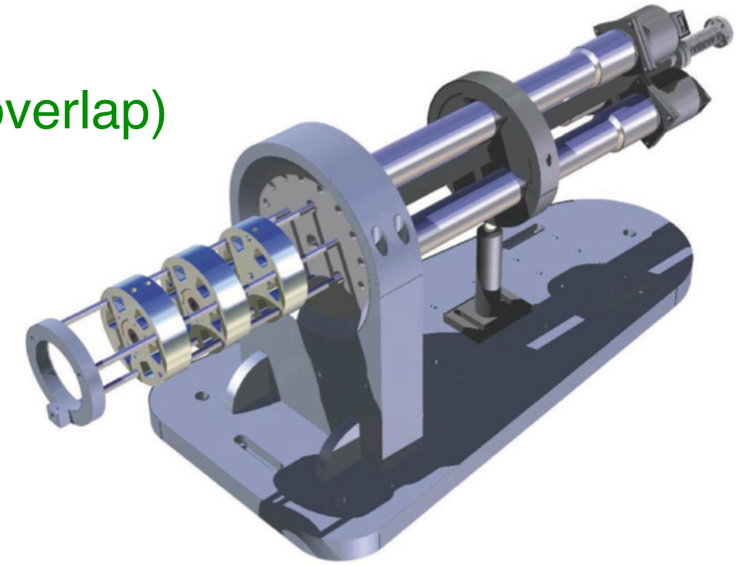
TCAV

- Undulator before plasma – pre-modulate beam (CO_2 better overlap)
- Seeds micro-modulation in plasma
- TCAV after after plasma – detects micro modulations

Possibilities to detect micro-modulations using TCAV ?



PMQ Triplet: (T-PMQ)

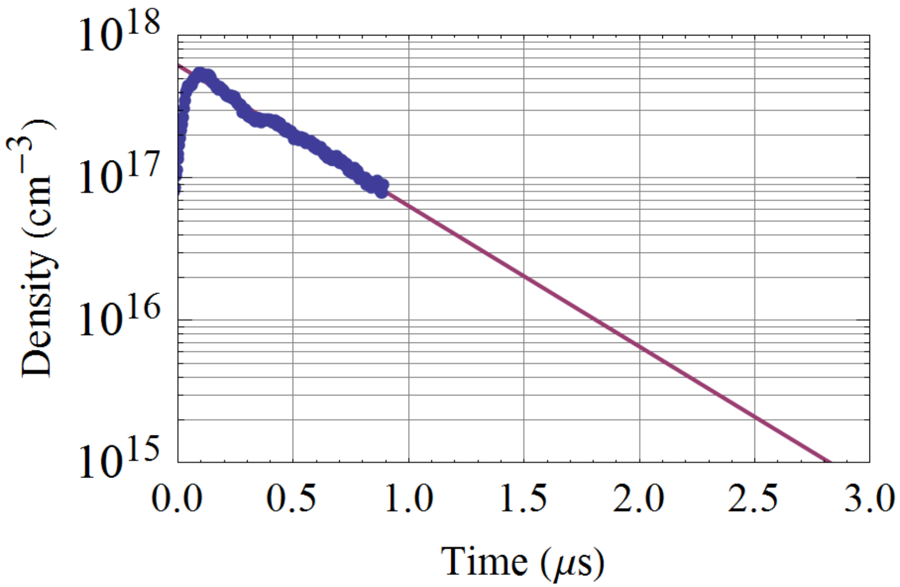
- require < 10um beam waist
- Adjustable focal length

Possibilities to go to smaller waist-sizes ?

Discharge capillary

- Discharge struck - plasma builds up to its highest density
- Density decays to lower values - over several µs
- Stationary conditions - few tens of ps e-beam traversing

Possibility to use an ionizing laser (<250mJ) ?



possibilities with **sub-fs** micro-modulation

- trends towards **attosecond** science – 10μm laser seed (spatial overlap)
- faster energy deposition in plasma by the micro-modulated beam
- use the micro-modulated beam to probe materials
- possibly excite solid-state modes (plasmons, phonons etc.)
- probe solid-state oscillations modes

University of Colorado Denver

Novel possibilities

with BNL-ATF

CO_2 Laser
Positron Acceleration

CO_2 Laser
RITA Ion acceleration

sub-fs modulated of e^- beam